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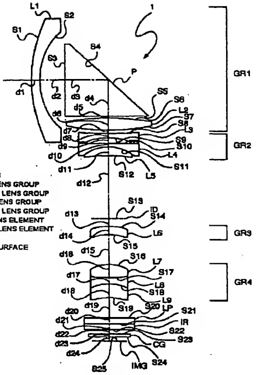
(54) **[Title of the Invention]** ZOOM LENS

(57) **[Abstract]**

[Objects] To provide a compact zoom lens having a zoom ratio of about 3 which is suitable for an image-taking apparatus such as a compact video camera or digital still camera.

[Features] A zoom lens is composed of, from the object side to the image plane IMG side, a first lens group GR1 having a positive refractive power, a second lens group GR2 having a negative refractive power, a third lens group having a positive refractive power, and a fourth lens group GR4 having a positive refractive power. Zooming is achieved by moving the second and fourth lens groups. The first lens group is composed of, from the object side, a first lens element L1, which is a single lens element having a negative refractive power, a prism P for bending the optical path, and a second lens element L2, which is a single lens element having a positive refractive power.



1··· ZOOM LENS
GR1··· FIRST LENS GROUP
GR2··· SECOND LENS GROUP
GR3··· THIRD LENS GROUP
GR4··· FOURTH LENS GROUP
L1··· FIRST LENS ELEMENT
L2··· SECOND LENS ELEMENT
P··· PRISM
IMG···IMAGE SURFACE

[Claims]

[Claim 1] A zoom lens comprising, from an object side to an image plane side,
a first lens group having a positive refractive power,
a second lens group having a negative refractive power,
a third lens group having a positive refractive power, and
a fourth lens group having a positive refractive power,
the second and fourth lens groups being moved to achieve zooming,

wherein the first lens group is composed of, from the object side, a first lens element, which is a single lens element having a negative refractive power, a prism for bending an optical path, and a second lens element, which is a single lens element having a positive refractive power.

[Claim 2] A zoom lens as claimed in claim 1, wherein the following conditions are fulfilled:

$ndL1 > 1.75$

$\nu dL1 < 30$

where

ndL1 represents a refractive index for the d-line of the first lens element, and

νdL1 represents an Abbe number for the d-line of the first lens element.

[Claim 3] A zoom lens as claimed in claim 1, wherein at least one of surfaces of the first lens element is an aspherical surface.

[Claim 4] A zoom lens as claimed in claim 1, wherein a surface of the first lens element facing the object side is a convex surface.

[Claim 5] A zoom lens as claimed in claim 2, wherein a surface of the first lens element facing the object side is a convex surface.

[Claim 6] A zoom lens as claimed in claim 3, wherein a surface of the first lens element facing the object side is a convex surface.

[Claim 7] A zoom lens as claimed in claim 1, wherein at least one of surfaces of lens elements constituting the fourth lens group is an aspherical surface.

[Claim 8] A zoom lens as claimed in claim 2, wherein at least one of surfaces of lens elements constituting the fourth lens group is an aspherical surface.

[Claim 9] A zoom lens as claimed in claim 3, wherein at least one of surfaces of lens elements constituting the fourth lens group is an aspherical surface.

[Claim 10] A zoom lens as claimed in claim 4, wherein at least one of surfaces of lens elements constituting the fourth lens group is an aspherical surface.

[Claim 11] A zoom lens as claimed in claim 5, wherein at least one of surfaces of lens elements constituting the fourth lens group is an aspherical surface.

[Claim 12] A zoom lens as claimed in claim 6, wherein at least one of surfaces of lens elements constituting the fourth lens group is an aspherical surface.

[Claim 13] A zoom lens as claimed in claim 1, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Claim 14] A zoom lens as claimed in claim 2, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Claim 15] A zoom lens as claimed in claim 3, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Claim 16] A zoom lens as claimed in claim 4, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Claim 17] A zoom lens as claimed in claim 5, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Claim 18] A zoom lens as claimed in claim 6, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Claim 19] A zoom lens as claimed in claim 7, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Claim 20] A zoom lens as claimed in claim 8, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Claim 21] A zoom lens as claimed in claim 9, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Claim 22] A zoom lens as claimed in claim 10, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Claim 23] A zoom lens as claimed in claim 11, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Claim 24] A zoom lens as claimed in claim 12, wherein the following condition is fulfilled:

$4.5 < f_{GR1} / fw < 12$

where

f_{GR1} represents a focal length of the first lens group, and

fw represents a focal length of the entire lens system at the wide-angle end.

[Detailed Description of the Invention]

[0001]

[Field of the Invention] The present invention relates to a zoom lens having a zoom ratio of about 3 which is suitable for a compact video camera, digital still camera, or the like.

[0002]

[Prior Art] In recent years, further miniaturization has been sought in compact image-taking apparatuses such as video cameras and digital still cameras, and accordingly further miniaturization has been sought in taking lenses, and in particular in zoom lenses, as by reducing their total lengths.

[0003] In such taking lenses, in particular in those for digital still cameras, not only miniaturization has been sought, but also there has been increasing demand for zoom lenses covering a wide-angle range of about 70 to 80° at the wide-angle end. Simultaneously, higher lens performance has been sought to cope with image sensors having higher and higher resolutions.

[0004]

[Problems to be Solved by the Invention] An example of a compact zoom lens for a compact image-taking apparatus is a two-lens-group zoom lens of a retrofocus type composed of, from the object side, a first lens group having a negative refractive power and a second lens group having a positive refractive power. However, with a two-lens-group zoom lens like this, it is difficult to obtain a high zoom ratio, and its total length varies as zooming is performed. This makes the zoom lens unsuitable for a compact image-taking apparatus.

[0005] Another example is a four-lens-group zoom lens composed of, from the object side, a first lens group having a positive refractive power, a second lens group (variator) having a negative refractive power, a third lens group (compensator) having a positive refractive power, and a fourth lens group (master) having a positive refractive power. However, with a four-

lens-group zoom lens like this, its total length is great. This makes the zoom lens unsuitable for a compact image-taking apparatus.

[0006] Another example, disclosed in Japanese Patent Application Laid-Open No. H8-248318, is a four-lens-group zoom lens composed of, from the object side, a first lens group having a positive refractive power, a second lens group (variator) having a negative refractive power, a third lens group (compensator) having a positive refractive power, and a fourth lens group (master) having a positive refractive power, wherein a prism is disposed between the object-side lens element and the other lens elements of the first lens group so that the first group is subdivided into an object-side group having a negative refractive power and an image-plane-side group having a positive refractive power to form an afocal system and that the prism bends the optical path to reduce the front-to-rear length. However, this type of zoom lens includes many lens elements, and still has a great total length, and is expensive to manufacture.

[0007] An object of the present invention is to provide a compact zoom lens having a zoom ratio of about 3 which is suitable for a compact image-taking apparatus such as a video camera or digital still camera.

[0008]

[Means for Solving the Problem] To achieve the above object, according to the present invention, in a zoom lens provided with, from the object side to the image plane side, a first lens group having a positive refractive power, a second lens group having a negative refractive power, a third lens group having a positive refractive power, and a fourth lens group having a positive refractive power, the second and fourth lens groups being moved to achieve zooming, the first lens group is composed of, from the object side, a first lens element, which is a single lens element having a negative refractive power, a prism for bending the optical path, and a second lens element, which is a single lens element having a positive refractive power.

[0009] This makes it possible to miniaturize a zoom lens having a zoom ratio of about 3 which is suitable for a compact image-taking apparatus such as a video camera or digital still camera.

[0010]

[Embodiments of the Invention] Hereinafter, zoom lenses embodying the present invention will be described with reference to the accompanying drawings. Figs. 1 to 4 show a first embodiment (Numerical Example 1), Figs. 5 to 8 show a second embodiment (Numerical Example 2), and Figs. 9 to 12 show a third embodiment (Numerical Example 3).

[0011] First, the features common to all the embodiments will be described.

[0012] In the following descriptions, "Si" represents the i-th surface from the object side, "Ri" represents the radius of curvature of the surface Si, "di" represents the axial distance between the i-th and (i + 1)th surfaces from the object side, "ndLi" represents the refractive index for the d-line (with a wavelength of 587.6 nm) of the i-th lens element (Li), νdLi represents the Abbe number for the d-line of the i-th lens element (Li), "f" represents the focal length of the entire lens system, "Fno." represents the open-aperture f-number, and "ω" represents the half view angle. A symbol "nd" or "νd" suffixed with P, LP, IR, or CG represents the refractive index or Abbe number of a prism, a low-pass filter, an infrared cut filter, or the cover glass of an image sensor, respectively.

[0013] In all the embodiments, the lens elements used include aspherical lens surfaces.

[0014] The shape of an aspherical surface is defined by

$$x = (y^2 / r) / 1 + (1 - \kappa \cdot y^2 / r^2)^{1/2} + C4 \cdot y^4 + C6 \cdot y^6 + C8 \cdot y^8 + C10 \cdot y^{10}$$

where "x" represents the depth (the distance from the vertex of the lens surface along the optical axis) of the aspherical surface, "r" represents the radius of curvature at the lens vertex, and "κ" represents the conic constant. C4, C6, C8, and C10 represent the aspherical surface coefficients of the forth, sixth, eighth, and tenth orders, respectively.

[0015] The zoom lenses 1, 2, and 3 of the first to third embodiments are all, as shown in Figs. 1, 5, and 9, composed of, from the object side to the image plane IMG side, a first lens group GR1 having a positive refractive power, a second lens group GR2 having a negative refractive power, a third lens group GR3 having a positive refractive power, and a fourth lens group GR4 having a positive refractive power. The zoom lenses 1, 2, and 3 all have a four-lens-group, nine-lens-element construction in which the first lens group GR1 is composed of two lens elements, namely a first lens element L1 and a second lens element L2, with a prism disposed between them, the second lens group GR2 is composed of three lens elements, namely a third lens element L3, a fourth lens element L4, and a fifth lens element L5, the third lens group GR3 is composed of a sixth lens element L6, and the fourth lens group GR4 is composed of three lens elements, namely a seventh lens element L7, an eighth lens element L8, and a ninth lens element L9.

[0016] Between the second and third lens groups GR2 and GR3, there is disposed an aperture stop ID. Between the fourth lens group GR4 and the image plane IMG, there are disposed, from the object side, a low-pass filter LP, an infrared cut filter IR, and the cover glass CG of a CCD.

[0017] Zooming is achieved by moving the second and fourth lens groups GR2 and GR4. As zooming is performed from the shortest-focal-length end (wide-angle end) to the longest-focal-length end (telephoto end), the second lens group GR2 moves from the object side to the image plane side, and the fourth lens group GR4 moves in such a way as to maintain the image position.

[0018] In the zoom lenses 1 to 3, focusing is achieved by moving the fourth lens group GR4.

[0019] The first lens group GR1 is composed of, from the object side, a first lens element L1, which is a meniscus-shaped single lens element having a negative refractive power, a prism P for bending the optical path at 90°, and a second lens element L2, which is a single lens element having a positive refractive power.

[0020] In the zoom lenses 1 to 3, it is preferable that conditional formulae 1 and 2 below be fulfilled, or alternatively that at least one of the surfaces of the first lens element L1 be an aspherical surface.

$ndL1 > 1.75$ (conditional formula 1)

$vdL1 < 30$ (conditional formula 2)

where ndL1 represents the refractive index for the d-line of the first lens element L1, and vdL1 represents the Abbe number for the d-line of the first lens element L1.

[0021] Conditional formula 1 defines the degree of distortion produced by the first lens element L1, which is provided in the first lens group GR1 having a positive refractive power and which itself has a negative refractive power. If the value of ndL1 is outside the range defined by conditional formula 1, giving the first lens group GR1 the desired refractive power results in producing too large distortion to be corrected by the aspherical surface in the fourth lens group GR4.

[0022] Conditional formula 2 defines the degree of chromatic aberration produced by the first lens element L1, which is provided in the first lens group GR1 having a positive refractive power and which itself has a negative refractive power. If the value of vdL1 is outside the range defined by conditional formula 2, the first lens group GR1 having a positive refractive power produces too large chromatic aberration to be corrected satisfactorily throughout the entire lens system.

[0023] In the zoom lenses 1 to 3, it is preferable that the object-side surface S1 of the first lens element L1 be convex to the object side. This is because, if this surface S1 is concave to the object side, it produces too large negative distortion to be corrected satisfactorily throughout the entire lens system.

[0024] In the zoom lenses 1 to 3, it is preferable that at least one of the surfaces of the lenses

constituting the fourth lens group GR4 be an aspherical surface, and it is particularly preferable that at least one of the surfaces of the lens element disposed at the image plane side end be an aspherical surface.

[0025] By making at least one of the lens surfaces within the fourth lens group GR4 aspherical in this way, it is possible to correct the negative distortion produced by the first lens group GR1 at the wide angle end. This makes it possible to give a strong power to the single lens element (first lens element) L1 that is provided in the first lens group GR1 and that has a negative refractive power. Thus, it is possible to obtain a wider angle of view.

[0026] In the zoom lenses 1 to 3, it is preferable that conditional formula 3 below be fulfilled.

$4.5 < f_{GR1} / fw < 12$ (conditional formula 3)

where f_{GR1} represents the focal length of the first lens group GR1, and fw represents the focal length of the entire lens system at the wide-angle end.

[0027] Conditional formula 3 defines the ratio of the focal length of the first lens group GR1 having a positive refractive power to the focal length of the entire lens system. If the value of f_{GR1} / fw is equal to or smaller than 4.5, the first lens group GR1 has too strong a positive power. This either makes it necessary to give a strong power to the second lens element L2, i.e. the single lens element that is provided in the first lens group GR1 and that has a positive refractive power, and thus makes it impossible to correct spherical aberration with the single lens element L2, or makes it necessary to give a weak power to the first lens element, i.e. the single lens element having a negative refractive power, and thus makes it difficult to obtain a satisfactorily wide angle of view. By contrast, if the value of f_{GR1} / fw is equal to or greater than 12, the first lens group GR1 has too weak a positive power, This makes the total length of the zoom lenses 1 to 3 unduly great, and thus makes miniaturization difficult.

[0028] Next, the features unique to each of the zoom lenses 1 to 3 of the first to third embodiments will be described.

[0029] Table 1 shows the numerical data of the zoom lens 1. A surface of which the symbol Ri is followed by (ASP) is an aspherical surface (the same is true also in Tables 4 and 7 described later).

[0030]

[Table 1]

R1=35.116	d1=1.8	ndL1=1.85000	νdL1=23.5
R2=16.675	d2=5.5		
R3=∞	d3=9.5	ndP=1.56883	νdP=56.0
R4=∞	d4=8.5	ndP=1.56883	νdP=56.0
R5=∞	d5=0.5		
R6=46.647	d6=2.8	ndL2=1.76811	νdL2=49.7
R7=-38.962	d7=variable		
R8=-64.828	d8=1.1	ndL3=1.84000	νdL3=43.0
R9=14.768	d9=1.1		
R10=140.620	d10=1.1	ndL4=1.75359	νdL4=51.6
R11=8.989	d11=2.0	ndL5=1.84666	νdL5=23.8
R12=33.286	d12=variable		
R13=∞	d13=1.5		
R14=9.334(ASP)	d14=2.0	ndL6=1.80610	νdL6=40.7
R15=12.687	d15=variable		
R16=7.522	d16=3.0	ndL7=1.75955	νdL7=50.8
R17=-40.255	d17=1.5	ndL8=1.84666	νdL8=23.8
R18=8.007	d18=8.8	ndL9=1.69350	νdL9=53.3
R19=24.197(ASP)	d19=variable		
R20=∞	d20=1.5	ndLP=1.55232	νdLP=63.4
R21=∞	d21=1.2	ndIR=1.51680	νdIR=64.2
R22=∞	d22=1.00		
R23=∞	d23=0.75	ndCG=1.55671	νdCG=58.6
R24=∞	d24=1.0		
R25=∞			

[0031] As shown in Table 1 above, in the zoom lens 1, as zooming and focusing are performed, the axial distances d7, d12, d15, and d19 vary (i.e., these are variable axial distances). Therefore, Table 2 shows the values of d7, d12, d15, and d19 along with the values of Fno., f, and ω as observed at each of the wide-angle end (f = 5.3), the telephoto end (f = 15.6), and the middle-focal-length position (f = 9.0) between the wide-angle end and the telephoto end.

[0032]

[Table 2]

f	5.3	9.0	15.5
FNo.	2.4	2.8	3.1
ω	37.0°	24.0°	14.5°
d7	0.8	8.36	13.76
d12	15.01	7.45	2.05
d15	7.02	4.96	2.0
d19	4.82	6.88	9.84

[0033] The object-side surface S14 of the sixth lens element L6 provided in the third lens group GR3 and the image-plane-side surface S19 of the ninth lens element L9 provided in the fourth lens group GR4 are aspherical surfaces. Table 3 below shows the aspherical surface coefficients C4, C6, C8, and C10 of the fourth, sixth, eighth, and tenth orders of those surfaces S14 and S19.

[0034]

[Table 3]

	κ	C4	C6	C8	C10
S14(R14)	0	-0.9142E-04	0.3775E-05	-0.4308E-08	0.1590E-07
S19(R19)	0	0.1217E-02	0.2458E-04	0.1236E-05	0.1235E-07

[0035] In Table 3 above, "E" denotes the exponential of 10 (the same is true also in Tables 7 and 11 described later).

[0036] Figs. 2 to 4 show diagrams showing the spherical aberration, astigmatism, and distortion observed in the zoom lens 1 at the wide-angle end, at the middle-focal-length position between the wide-angle end and the telephoto end, and at the telephoto end, respectively. In the diagrams showing spherical aberration, the solid line represents the data observed for the e-line (having a wavelength of 546.1 nm), the dotted line (broken line with short strokes) the data observed for the C-line (having a wavelength of 656.3 nm), the dash-dot line the data observed for the d-line, the broken line the data observed for the F-line (having a wavelength of 486.1 nm), and the dash-dot-dot line the data observed for the g-line (having a wavelength of 435.8 nm). In the diagrams showing astigmatism, the solid line and the broken line represent the data observed on the sagittal and meridional image planes, respectively.

[0037] In the zoom lens 1 described above, the fourth lens group GR4 is built by cementing together three lens elements L7, L8, an L9. This helps reduce the inclination of the image plane resulting from decentering occurring within the fourth lens group GR4, and helps facilitate fabrication.

[0038] Table 4 shows the numerical data of the zoom lens 2.

[0039]

[Table 4]

R1=43.203	d1=2.0	ndL1=1.84666	νdL1=23.8
R2=16.054	d2=4.0		
R3=∞	d3=9.5	ndP=1.56883	νdP=56.0
R4=∞	d4=8.5	ndP=1.56883	νdP=56.0
R5=∞	d5=0.5		
R6=40.072	d6=2.3	ndL2=1.83500	νdL2=43.0
R7=-40.072	d7=variable		
R8=-130.120	d8=1.1	ndL3=1.83500	νdL3=43.0
R9=11.909	d9=1.29		
R10=∞	d10=1.0	ndL4=1.75359	νdL4=51.6
R11=7.755	d11=2.2	ndL5=1.84666	νdL5=23.8
R12=31.164	d12=variable		
R13=∞	d13=1.5		
R14=9.845(ASP)	d14=1.5	ndL6=1.69350	νdL6=53.3
R15=13.742	d15=variable		
R16=9.050	d16=2.5	ndL7=1.69350	νdL7=53.3
R17=-9.050	d17=1.0	ndL8=1.84666	νdL8=23.8
R18=-104.131	d18=4.75		
R19=35.698(ASP)	d19=1.0	ndL9=1.49200	νdL9=57.2
R20=24.197(ASP)	d20=variable		
R21=∞	d21=1.5	ndLP=1.55232	νdLP=63.4
R22=∞	d22=1.2	ndIR=1.51680	νdIR=64.2
R23=∞	d23=1.0		
R24=∞	d24=0.75	ndCG=1.55671	νdCG=58.6
R25=∞	d25=1.0		
R26=∞			

[0040] As shown in Table 4 above, in the zoom lens 2, as zooming and focusing are performed, the axial distances d7, d12, d15, and d20 vary (i.e., these are variable axial distances). Therefore, Table 5 shows the values of d7, d12, d15, and d20 along with the values of Fno., f, and ω as observed at each of the wide-angle end (f = 5.3), the telephoto end (f = 15.5), and the middle-focal-length position (f = 9.0) between the wide-angle end and the telephoto end.

[0041]

[Table 5]

f	5.3	9.0	15.5
FNo.	2.8	3.1	3.8
ω	37.0°	24.0°	14.5°
d7	0.8	7.17	11.4
d12	12.65	6.28	2.05
d15	8.99	6.09	2.0
d20	3.67	6.57	10.66

[0042] The object-side surface S14 of the sixth lens element L6 provided in the third lens group GR3 and the object-side and image-plane-side surfaces S19 and S20 of the ninth lens element L9 provided in the fourth lens group GR4 are aspherical surfaces. Table 6 below shows the aspherical surface coefficients C4, C6, C8, and C10 of the fourth, sixth, eighth, and tenth orders of those surfaces S14, S19, and S20.

[0043]

[Table 6]

	κ	C4	C6	C8	C10
S14(R14)	0	-0.1224E-03	0.9870E-05	-0.1144E-05	0.4671E-07
S19(R19)	0	-0.9497E-03	0.3720E-04	-0.6771E-05	0.3284E-06
S20(R20)	0	-0.5412E-04	0.7292E-04	-0.8809E-05	0.4580E-06

[0044] Figs. 6 to 8 show diagrams showing the spherical aberration, astigmatism, and distortion observed in the zoom lens 2 at the wide-angle end, at the middle-focal-length position between the wide-angle end and the telephoto end, and at the telephoto end, respectively. In the diagrams showing spherical aberration, the solid line represents the data observed for the e-line, the dotted line the data observed for the C-line, the dash-dot line the data observed for the d-line, the broken line the data observed for the F-line, and the dash-dot-dot line the data observed for the g-line. In the diagrams showing astigmatism, the solid line and the broken line represent the data observed on the sagittal and meridional image planes, respectively.

[0045] In the zoom lens 2, an aspherical-surface lens element made of plastic is used as the ninth lens element L9 provided in the fourth lens group GR4. This helps achieve miniaturization and high performance, and helps realize a zoom lens that is inexpensive to manufacture.

[0046] Table 7 shows the numerical data of the zoom lens 3.

[0047]

[Table 7]

R1=35.641	d1=1.8	ndL1=1.85000	νdL1=23.6
R2=16.216(ASP)	d2=5.5		
R3=∞	d3=9.5	ndP=1.56883	νdP=56.0
R4=∞	d4=8.5	ndP=1.56883	νdP=56.0
R5=∞	d5=0.5		
R6=32.206	d6=2.8	ndL2=1.76856	νdL2=49.9
R7=-56.283	d7=variable		
R8=-53.723	d8=1.1	ndL3=1.84000	νdL3=43.0
R9=17.458	d9=1.1		
R10=∞	d10=1.0	ndL4=1.84000	νdL4=43.0
R11=7.883	d11=2.0	ndL5=1.83916	νdL5=23.8
R12=48.420	d12=variable		
R13=∞	d13=1.5		
R14=18.484(ASP)	d14=2.0	ndL6=1.80610	νdL6=40.7
R15=15.066	d15=variable		
R16=7.899	d16=3.0	ndL7=1.79554	νdL7=46.8
R17=-33.011	d17=1.5	ndL8=1.80688	νdL8=25.6
R18=6.097	d18=3.3	ndL9=1.69850	νdL9=53.3
R19=22.085(ASP)	d19=variable		
R20=∞	d20=1.5	ndLP=1.55282	νdLP=68.4
R21=∞	d21=1.2	ndIR=1.51680	νdIR=64.2
R22=∞	d22=1.0		
R23=∞	d23=0.75	ndCG=1.55671	νdCG=58.6
R24=∞	d24=1.0		
R25=∞			

[0048] As shown in Table 7 above, in the zoom lens 3, as zooming and focusing are performed, the axial distances d7, d12, d15, and d19 vary (i.e., these are variable axial distances). Therefore, Table 8 shows the values of d7, d12, d15, and d19 along with the values of Fno., f, and ω as observed at each of the wide-angle end (f = 5.3), the telephoto end (f = 15.5), and the middle-focal-length position (f = 9.0) between the wide-angle end and the telephoto end.

[0049]

[Table 8]

f	5.3	9.0	15.5
FNo.	2.4	2.6	3.1
ω	37.0°	24.0°	14.5°
d7	0.8	8.08	13.2
d12	14.41	7.12	2.0
d15	7.26	5.11	2.0
d19	5.19	7.34	10.45

[0050] The image-plane-side surface S2 of the first lens element L1 provided in the first lens group, the object-side surface S14 of the sixth lens element L6 provided in the third lens group GR3, and the image-plane-side surface S19 of the ninth lens element L9 provided in the fourth lens group GR4 are aspherical surfaces. Table 3 below shows the aspherical surface coefficients C4, C6, C8, and C10 of the fourth, sixth, eighth, and tenth orders of those surfaces S2, S14, and S19.

[0051]

[Table 9]

	κ	C4	C6	C8	C10
S2(R2)	0	-0.4475E-05	0.2083E-07	-0.6283E-10	-0.7920E-12
S14(R14)	0	-0.6561E-04	0.1709E-05	-0.1885E-06	0.6981E-08
S19(R19)	0	0.1058E-02	0.2442E-04	0.4787E-06	0.3475E-07

[0052] In the zoom lens 3, as described above, an aspherical surface is used as the image-plane-side surface L2 of the first lens element L1 provided in the first lens group GR1. This helps correct curvature of field and the spherical aberration appearing in the long-focal-length range.

[0053] Figs. 10 to 12 show diagrams showing the spherical aberration, astigmatism, and distortion observed in the zoom lens 3 at the wide-angle end, at the middle-focal-length position between the wide-angle end and the telephoto end, and at the telephoto end, respectively. In the diagrams showing spherical aberration, the solid line represents the data observed for the e-line, the dotted line the data observed for the C-line, the dash-dot line the data observed for the d-line, the broken line the data observed for the F-line, and the dash-dot-dot line the data observed for the g-line. In the diagrams showing astigmatism, the solid line and the broken line represent the data observed on the sagittal and meridional image planes, respectively.

[0054] In the zoom lens 3 described above, as in the zoom lens 1 of the first embodiment, the fourth lens group GR4 is built by cementing together three lens elements L7, L8, an L9. This helps reduce the inclination of the image plane resulting from decentering occurring within the fourth lens group GR4, and helps facilitate fabrication.

[0055] Table 10 below shows the values necessary to calculate the conditions 1 to 3 and the values of the conditional formulae themselves as actually observed in each of the zoom lenses 1 to 3 of the first to third embodiments.

[0056]

[Table 10]

EMBODIMENT	n_{dL1}	ν_{dL1}	f_{GR1}	f_W	f_{GR1}/f_W
1	1.85000	23.5	38.29	5.3	7.22
2	1.84666	23.8	32.99	5.3	6.22
3	1.85000	23.5	36.94	5.3	6.97

[0057] As will be clear from Table 10 above, the zoom lenses 1 to 3 all fulfill the conditions defined by conditional formulae 1 to 3. Moreover, as will be seen from the aberration diagrams, in the zoom lenses 1 to 3, various aberrations are corrected with a proper balance at the wide-angle end, at the middle-focal-length position between the wide-angle end and the telephoto end, and at the telephoto end.

[0058] As described above, the zoom lenses 1 to 3 all have an angle of view of 74° at the wide-angle end, thus covering a sufficiently wide-angle region, and have various aberrations corrected properly. This makes the zoom lenses 1 to 3 suitable for digital still cameras provided with a high-resolution image sensor.

[0059] It is to be understood that the shapes and structures of the details specifically presented in the embodiments described above are mere examples of how the present invention is carried out, and thus are not to be regarded as limiting the technical scope of the invention in any way.

[0060]

[Advantages of the Invention] As will be clear from what has been described hereinbefore, according to the present invention, in a zoom lens provided with, from the object side to the image plane side, a first lens group having a positive refractive power, a second lens group having a negative refractive power, a third lens group having a positive refractive power, and a fourth lens group having a positive refractive power, the second and fourth lens groups being moved to achieve zooming, the first lens group is composed of, from the object side, a first lens element, which is a single lens element having a negative refractive power, a prism for bending the optical path, and a second lens element, which is a single lens element having a positive refractive power. This makes it possible to miniaturize a zoom lens having a zoom ratio of about 3 which is suitable for a compact image-taking apparatus such as a video camera or digital still camera.

[0061] In the zoom lens recited in claim 2, let ndL1 be the refractive index for the d-line of the first lens element, and let vdL1 be the Abbe number for the d-line of the first lens element, then the conditions ndL1 > 1.75 and vdL1 < 30 are fulfilled. This makes it possible to properly correct the distortion and chromatic aberration produced by the first lens group.

[0062] In the zoom lens recited in claim 3, at least one of the surfaces of the first lens element is an aspherical surface. This makes it possible to properly correct curvature of field and the spherical aberration appearing in a long-focal-length region.

[0063] In the zoom lenses recited in claims 4 to 6, the surface of the first lens element facing the object side is a convex surface. This helps prevent negative distortion, which is difficult to correct through the entire lens system, from becoming unduly large.

[0064] In the zoom lenses recited in claims 7 to 12, at least one of the surfaces of the lens elements constituting the fourth lens group is an aspherical surface. This makes it possible to effectively correct the negative distortion produced by the first lens group at the wide-angle end. As a result, it is possible to give a strong power to the negative single lens element provided in the first lens group, and thereby obtain a wider angle of view.

[0065] In the zoom lenses recited in claims 13 to 24, let f_{GR1} be the focal length of the first lens group, and let fw be the focal length of the entire lens system at the wide-angle end, then the condition $4.5 < f_{GR1} / fw < 12$ is fulfilled. This makes it possible to achieve proper correction of spherical aberration, a satisfactorily wide angle of view, and satisfactory miniaturization.

[Brief Description of the Drawings]

[Fig. 1] A diagram showing, together with Figs. 2 to 4, the zoom lens of a first embodiment of the invention, schematically showing the lens construction.

[Fig. 2] Diagrams showing the spherical aberration, astigmatism, and distortion observed at the wide-angle end.

[Fig. 3] Diagrams showing the spherical aberration, astigmatism, and distortion observed at the middle-focal-length position between the wide-angle end and the telephoto end.

[Fig. 4] Diagrams showing the spherical aberration, astigmatism, and distortion observed at the telephoto end.

[Fig. 5] A diagram showing, together with Figs. 6 to 8, the zoom lens of a second embodiment of the invention, schematically showing the lens construction.

[Fig. 6] Diagrams showing the spherical aberration, astigmatism, and distortion observed at the wide-angle end.

[Fig. 7] Diagrams showing the spherical aberration, astigmatism, and distortion observed at the middle-focal-length position between the wide-angle end and the telephoto end.

[Fig. 8] Diagrams showing the spherical aberration, astigmatism, and distortion observed at the telephoto end.

[Fig. 9] A diagram showing, together with Figs. 10 to 12, the zoom lens of a third embodiment of the invention, schematically showing the lens construction.

[Fig. 10] Diagrams showing the spherical aberration, astigmatism, and distortion observed at the wide-angle end.

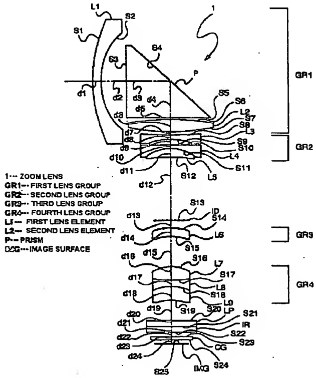
[Fig. 11] Diagrams showing the spherical aberration, astigmatism, and distortion observed at the middle-focal-length position between the wide-angle end and the telephoto end.

[Fig. 12] Diagrams showing the spherical aberration, astigmatism, and distortion observed at the telephoto end.

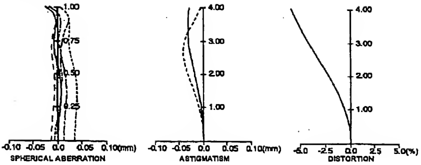
[Description of the Reference Designations]

1: zoom lens, 2: zoom lens, 3: zoom lens, GR1: first lens group, GR2: second lens group, GR3: third lens group, GR4: fourth lens group, L1: first lens element, L2: second lens element, P: prism, and IMG: image plane.

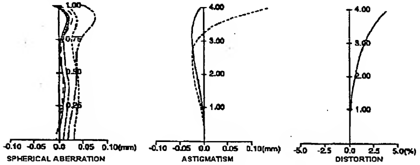
[Fig. 1]



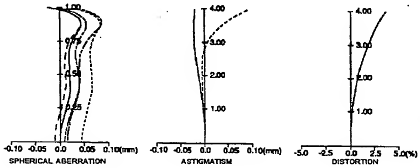
[Fig. 2]



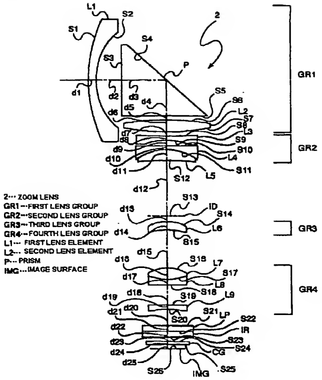
[Fig. 3]



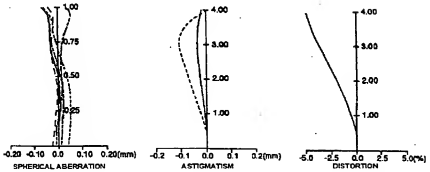
[Fig. 4]



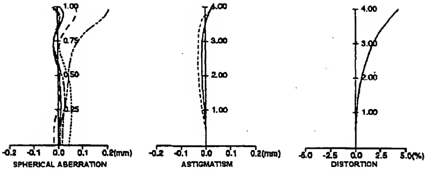
[Fig. 5]


2··· ZOOM LENS
GR1···FIRST LENS GROUP
GR2···SECOND LENS GROUP
GR3···THIRD LENS GROUP
GR4···FOURTH LENS GROUP
L1··· FIRST LENS ELEMENT
L2··· SECOND LENS ELEMENT
P··· PRISM
IMG···IMAGE SURFACE
GR1
GR2
GR3
GR4

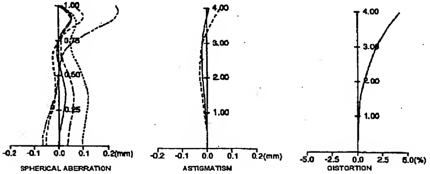
[Fig. 6]


SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION

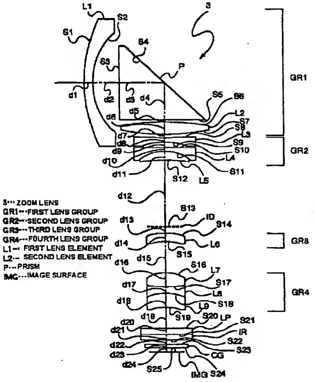
[Fig. 7]



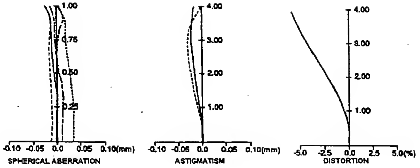
[Fig. 8]



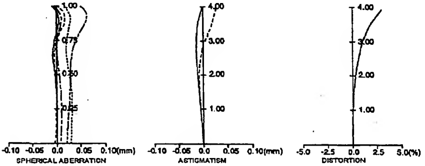
[Fig. 9]



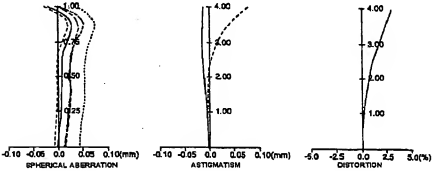
[Fig. 10]



[Fig. 11]



[Fig. 12]



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F Term (for reference) 2H087 . . . [omitted]